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Analysis of the entrainment on lock-exchange density currents

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Density or gravity currents are geophysical flows driven by density differences within a fluid which can be caused by temperature differences or the presence of dissolved substances or particles in suspension. Oceanic fronts and turbidity currents in lakes and reservoirs are examples of gravity currents occurring in masses of water. In the governing equations of density currents, namely in the total mass conservation equation, the entrainment rate of the ambient fluid through the upper interface becomes an explicit or source term requiring a closure model. The entrainment rate may be modelled as a function of the buoyancy velocity and a characteristic density, and it is usually evaluated through empirical relations. The aim of the present work is to experimentally investigate the entrainment of ambient fluid into unsteady density currents performed by lock-exchange releases of saline water into a fresh water tank. The experiments were conducted at the Laboratory of Hydraulics of University of Rome “Roma Tre” in a 3.0 m long, 0.20 m wide and 0.30 m deep transparent Perspex flume. Eight lockexchange release tests were performed varying the density of the saline water, the water depth in the water tank and the bed roughness. The experiments were performed by varying one parameter at a time. For smooth bed and for a fixed value of water depth, h = 0.20 m, four different initial densities of the salt-water mixture were analysed: 1015, 1030, 1045 and 1060 kg/m^3; for a fixed initial density of 1030 kg/m^3, one test was performed by changing the water depth to 0.25 m; the effect of bed roughness was investigated for a fixed water depth and fixed density, 1030 kg/m^3, by placing a thick layer of sediments on the bed with three different values of D_{50}: 2.9 mm, 4.6 mm and 24.6 mm, where D_{50} is the grain size diameter for which 50% of the sediments have smaller diameters. A controlled quantity of dye is added to the saline water in the lock to provide flow visualization and to serve as density tracer. The development of the current is recorded with a 25 Hz CCD camera under controlled light conditions. The resulting video frames are thus converted into gray scale matrices and a calibration procedure establishes a non-linear relation, experimentally determined, between the gray scale values and the quantity of dye in the water. The quantity of dye is converted into salt concentration by assuming a linear relation between quantities, dye and salt, allowing thus the estimation of the 2D instantaneous current density distribution. With the resulting 2D density maps, temporal and spatial evolution of the current height and depthaveraged density and temporal evolution of the front position, front velocity, mass balance and entrainment rate may be assessed and discussed taking into account the differences in the initial density of the saltwater mixture, the water depth and bed roughness. Detailed reconstruction of the current 2D geometry is possible, allowing the identification of such phenomena as instabilities in the upper mixing layer; these are observed in the plots of current height and instantaneous density maps, and may be related with the process of water entrainment. They prove to be quasi-stationary, or at least varying at a different (lower) time scale than the remainder current, being slightly advected downstream by the mean current velocity.

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